ORD LEAD RESEARCH OVERVIEW

Planned Research and Recent Accomplishments

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Abstract

The following is a resource that provides a brief overview of EPA's Office of Research and Development planned lead research, technical support, and recent accomplishments

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Contents

Introduction: EPA Lead Research and the Federal Action Plan to Reduce Childhood Lead Exposure and Associated Health Impacts

The Federal Action Plan to Reduce Childhood Lead Exposures and Associated Health Impacts was produced by the President's Task Force on Environmental Health Risks and Safety Risks to Children, comprised of 17 Federal Agencies and co-led by EPA. It is a blueprint to reduce lead exposure and associated harms to children. EPA's Office of Research and Development (ORD), HUD, and HHS have taken the lead on developing science and technology to support efforts to reduce lead exposures and related health risks. ORD's lead research is distributed over multiple National Research and Regional Science Programs ([HYPERLINK \l "_Table_1:_ORD's"]). ORD is working to strengthen the scientific basis of the Agency's lead-related regulatory and cleanup decisions; identify locations of high exposures and blood lead levels to target remaining lead sources for mitigation; and develop innovative methods for cleaning up Superfund and other contaminated sites.

> Goal 1: Reduce Children's exposure to lead sources
> Goal 2: Identify lead-exposed children and improve their health outcomes
> Goal 3: Communicate more effectively with stakeholders
> **Goal 4: Support and conduct critical research to inform efforts to reduce lead exposures and related health risks**
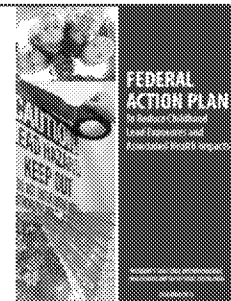
ORD's current actions include:

- Generating data and updating models to better understand source apportionment and predict the impact of risk reduction actions on blood lead levels in children, adolescents, and adults.
- Developing rapid, inexpensive tests to evaluate the level of soil cleanup needed at specific contaminated sites.
- Identifying innovative ways to mitigate lead exposure risk using soil amendments and other technologies.
- Demonstrating, in conjunction with EPA's Regions and state and local health departments, that cleaning up lead at Superfund sites has measurable impacts, reducing the numbers of children with elevated blood lead levels living in nearby communities.
- Identifying and mapping high exposure communities and analyzing for potential lead sources within those communities using geospatial methods and models in collaboration with and support of EPA Regional Offices, states, and tribes.
- Improving drinking water quality across the United States, in collaboration with states, tribes, and municipalities, by:
    - Developing methods to help communities to locate lead service lines.
    - Evaluating corrosion control treatments for water systems that still have lead service lines or plumbing fixtures containing lead to reduce the leaching of lead into drinking water.
    - Providing technical support by reviewing corrosion control plans and providing recommendations to municipalities that have identified issues in their water distribution systems.

This overview describes ORD research focused on reducing lead exposures and remediating contaminated sites for FY2020-FY2022 and provides an annotated bibliography of recent lead research accomplishments. Each section lists lead research products that have been planned in consultation with EPA's Program and Regional Offices, with input from the states. These are organized by ORD strategic research area and output and include reference numbers for ORD's RAPID Research Tracking system.

Health and Ecological Risk Assessment

Research Area: Science Assessment Translation

Output: Technical Support to EPA Regions and states through the STSC and ERASC (HERA.2.1)

HERA will continue to provide and conduct technical assistance and support in the area of human health and ecological risk assessment for EPA's program offices and regions related to issues of concern at Superfund, Resource Conservation and Recovery Act (RCRA), and Brownfield sites. HERA manages two of the five ORD Technical Support Centers (TSCs), dedicated to serving the EPA and its clients by supplying high-quality, quick-response technical support services when the scope of work is beyond what is available to the Regions, Program Offices, States and Tribes. The Superfund Health Risk Technical Support Center (STSC) provides scientific/technical support in the area of human health risk assessment to support States, Regions, and associates on Superfund related issues, including interpretation of guidance and assessments, complex analyses of surrogate chemicals for data poor chemicals of concern, and evaluation of published health values from EPA and other Agencies (e.g., ATSDR). The STSC provides quarterly updates, annual reports, and often complex responses to requests in order to ensure the partners and stakeholders have the information necessary to protect public health in contaminated communities. The Ecological Risk Assessment Support Center (ERASC) provides state-of-the-science technical information through the development of reports that address broad issues of concern relevant to ecological risk assessments and cleanups at contaminated sites including Superfund and RCRA. This output encompasses the support, reporting, and engagement activities necessary to provide the technical support and expertise upon requests through the STSC and ERASC.

Product

Evaluation of Health Impacts of Lead Remediation at ASARCO Superfund Site (Planned delivery: FY2020)

From EPA Science Matters

[HYPERLINK \l "_Reducing_Children's_Lead"]

Health and Ecological Risk Assessment

Research Area: Essential Assessment and Infrastructure Tools
Output: Innovate, develop, and maintain a suite of essential software and support tools for risk assessment (HERA.4.1)

Program office partners rely upon science assessments developed as part of the HERA portfolio to inform policies and regulations. Development of these assessments that must be rigorous, timely, and transparent requires infrastructure, including software tools and databases, that facilitate systematic review methodologies. While the HERA portfolio includes assessments for diverse partners across an array of scientific disciplines with multiple evidence streams, assessment development, conceptually, is comprised of the same set of steps: identification and screening of literature/evidence, data extraction, study quality evaluation, synthesis, evidence integration, and presentation of conclusions. As systematic review is further adapted and implemented across the portfolio of products, as described in Output 3.4, maintaining existing infrastructure and continuing development as assessment needs emerge will be critical. This Output relates to each step of the assessment process. Existing tools and databases that have historically supported assessment development (e.g., Health and Environmental Research Online [HERO] database) will continue to be maintained. However, as new tools and approaches are conceived of based on assessment needs, this Output will also provide support to develop new infrastructure and ensure that there is interoperability of the tools and databases (e.g., Health Assessment Workspace Collaborative [HAWC]). This infrastructure consisting of tools and databases and their interoperability will contribute to more seamless assessment workflows and yield greater efficiency and consistency in delivering assessments to partners and stakeholders.

Product

Support, evaluation, and review for lead biokinetic models (Planned delivery: FY2021)

FY2019 Accomplishments (Linked to Appendix)

- [HYPERLINK \l "_Estimates_of_urinary"]
- [HYPERLINK "https://yosemite.epa.gov/sab/sabproduct.nsf/MeetingCal/EE5CFDC1E94D505D8525847E005264ED?OpenDocument"][1] including:
  - External Review Draft of AALM Version 2.0:
    - Technical Documentation
    - Users Guide for the FORTRAN Version of the All-Ages Lead Model (April 2019)
    - The AALM Version 2.0 Software

From EPA Science Matters:

[HYPERLINK \l "_EPA_Leads_the"]

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[1] Link to internet, checked 01/10/2020

Safe and Sustainable Waters Research Program

Research Area: Drinking Water and Water Distribution Systems (SSWR.7)

Output: Resources and tools for characterizing and mitigating lead (Pb) and copper (Cu) release in drinking water distribution systems and premise plumbing (SSWR.7.20).

This output will provide research on source contributions from lead-containing plumbing materials under varying water quality conditions and scale properties. This output will also develop improved sampling and detection strategies, including those to identify lead service lines, and will include corrosion control strategies for minimizing copper pitting and release in water-delivery systems. This research will be integrated into models that estimate lead exposure and into remediation strategies to protect public health. Results from this research will inform the Federal Lead Strategy and will help states and utilities reduce human exposure to lead.

Products (Start date, planned delivery date) and sub-products (planned delivery date):

Treatment strategies for reducing lead and copper in drinking water (FY2020, FY2022)
1. Properties and Solubility of Pb Phosphate Particles (2020)
2. Lead Solubility Model Revisited (2021)
3. Impact of Polyphosphate and Silicate on Copper Solubility and Particles (2022)
4. Impact of Polyphosphate and Silicate on Lead Solubility and Particles (2022)

Lead exposure assessment and modeling tools (FY2020, FY2022)
1. Predicting Water Quality Problems in Premise Plumbing Systems with Agent-Based Modeling (2020)
2. Predicting Lead Sampling Efficacy Using Premise Plumbing Models for Single Family Homes (2021)
3. Sampling Approaches to Estimate Lead Exposure through Drinking Water (2021)
4. Development of premise plumbing Pb model (2021)
5. Development of a Water Sampling-Based Method to Identify Lead Service Lines (2020)
6. Predicting Water Lead Concentrations within Premise Plumbing Systems for Single Family Homes (2022)

Lead and copper source characterization and assessment strategies (FY2020, FY2022)
1. Evaluation of Lead Pipe Scale and Orthophosphate Treatment (2020)
2. High Lead Release from Dissolution of PbO2 after Extended Periods of Lack of Water Use (2020)
3. Lead Service Line Scale Analysis as a Tool for Water Systems (2020)
4. Methodology and Pitfalls of Lead Service Line Scale Analyses (2020)
5. Lead Pipe Scale Analysis Importance and Methodology (2021)
6. Lead Speciation in Amorphous Lead Pipe Scales Using Synchrotron Methods (2022)
7. Microbiological Community Structure and Function Analysis of Biofilm Associated with Lead Service Lines (2022)

Lead and copper sampling and monitoring tools (FY2020, FY2021)
1. Methodology and Pitfalls of Lead Service Line Scale Analyses (2020)
2. Lead Pipe Scale Analysis Importance and Methodology (2021)
3. Lead Speciation in Amorphous Lead Pipe Scales Using Synchrotron Methods (2022)
4. Microbiological Community Structure and Function Analysis of Biofilm Associated with Lead Service Lines (2022)
5. Field Analyzers for Lead Quantification in Drinking Water: A Literature Review (2021)
6. Field Study to Comparing Water Sampling Protocols for Lead Assessment (2022)

7. A Water Sampling Device for Assessing the Presence of LSLs (2022)

FY2019 Accomplishments (hyperlinked to Appendix):

* [HYPERLINK \l "_POU_Water_Filters_1"]
* [HYPERLINK \l "_Dietary_Lead_and"][HYPERLINK \l "_Sequential_Drinking_Water_1"]

[HYPERLINK \l "_Water_quality-pipe_deposit"][HYPERLINK \l "_Design_and_Testing"]**From EPA Science Matters:**

[HYPERLINK \l "_Revealing_the_Complicated"][HYPERLINK \l "_Identifying_the_Best"]

Safe and Sustainable Waters Research Program

Research Area: Technical Support (SSWR.11)

OUTPUT: Technical support for water treatment, analytical methods, and risk assessments (SSWR.11.31)

This site-specific technical support research component bridges the gap between emergency response, under the purview of the EPA regions and CESER, and longer-term ORD research studies with the EPA regions, states, and OW. The estimated time frame of extramural technical support is 2-4 weeks. ORD provides assistance to the Agency, states, and communities during events involving high priority drinking water contaminants. A recent example is ORD's support to the Michigan Department of Environmental Quality during the Flint, Michigan water crisis, where EPA engineers provided onsite technical support and analytical lab support. ORD provides timely scientific support and focus on critical aspects requested by stakeholders through support contracts accessible to ORD, the regions, and OW. These expedite the effectiveness and speed at which ORD can collect and/or transport samples and provide support while minimizing the impact to researchers engaged in ongoing research. The Annual EPA Drinking Water Workshop and the Monthly Small Systems Webinar Series provide in-depth information and training on various solutions and strategies for handling small system challenges.

Products (Planned delivery date):

Technical support to EPA partners and communities to rapidly respond to high priority drinking water contaminant issues (Summary Reports: FY2020, FY2021, FY2022). **This includes:**

1. Field sampling support for collecting multi-media samples
2. Field sampling to acquire required physical information about sampling sites
3. Laboratory analytical support
4. Field data, records collection, and data management support from collaborating stakeholders
5. Data-based models to generate guidance for the state, community, tribe, etc.
6. Training on solutions for small drinking water system challenges (Annual Workshop and Webinar Reports: FY2020, FY2021, FY2022)

Current Locations for technical support on lead in drinking water:

- Newark NJ – Current support to Region 2, NJ DEP, municipality: Consultation on corrosion control; Technical support has included drinking water sampling and analysis of efficacy of point-of-use water filters. Initial request by: Newark, NJ and their contractor; Initiated: January 2019
- University Park IL – Current support to Region 5, IL DEP, municipality: Corrosion control: elevated drinking water lead levels due to changes in water chemistry interacting with existing plumbing fixtures. Initial request by: Region 5; Initiated: Spring 2019
- Pittsburgh PA – Current support to Region 3, municipality: Corrosion control, infrastructure resilience. Initial request by: OW; Initiated: 2018
- Providence RI – Current support to Region 1, municipality: Service on expert panel. Initial request by: Providence, RI; Initiated: 10+ years ago
- Menasha WI – Current support to Region 5, municipality: Pipe scale analysis. Initiated 2015 through R5 Regional Applied Research (RARE) program.

Sustainable and Healthy Communities Research Program

Research Area: Chemicals of Immediate Concern: Lead (SHC.5)
OUTPUT: Collaborative Science-Based Approaches and Results to Identify High Lead (Pb) Exposure Locations in the U.S. and Key Drivers at those Locations (SHC.5.1)

This Output will produce collaborative science-based approaches and apply results to identify high lead (Pb) exposure locations in the U.S. and key drivers (e.g. housing-related and environmental sources) at those locations. The approaches will be developed and enhanced iteratively, using available housing, sociodemographic, environmental, and states' blood lead level (BLL) data at census tract level in new applications of geospatial and statistical methods and models. New map layers will be developed for Pb sources at different geospatial scales, for use in Pb modeling and mapping. Collaborative engagement with EPA Regional and Program Offices, State and Federal partners, and others will be critical to this Output to produce results informing EPA/stakeholder joint planning discussions. Results will include geospatial data for visualizing high Pb exposure locations, and data analyses to help identify key drivers at those locations and inform effective targeting and exposure reduction efforts. This Output responds Federal Lead Action Plan Goal 4, action 2: "Generate data, maps, and mapping tools to identify high exposure communities or locations." Identifying locations with highest potential for children's exposures and blood lead levels will assist with targeting and prioritization for lead exposure risk reduction, prevention, and mitigation efforts.

Products (Start date, planned delivery date) and sub-products (planned delivery date):

Development and application of methods for identifying high exposure lead (Pb) locations and the key drivers at those locations (FY2018, FY2021)

1. ORD journal manuscript on MI Pb geospatial and modeling data analyses (2020)
2. ORD journal manuscript on OH Pb geospatial/modeling data analyses (2020)
3. ASTHO/ECOS/ORD MOA pilot webinar with states and other deliverables on data sharing and risk communication (2020)
4. Incorporation of data from HUD, CDC, and other partners through interagency collaborations (2020)
5. Interagency (HUD, CDC) journal manuscript on scientific approaches and challenges for identifying high Pb exposure locations and the key drivers (2021)

Technical support to Regions to identify high lead exposure locations and key drivers in those locations (FY2020, FY2021)

6. Follow-up meetings with regional offices and their state partners as the methods are refined and more data are shared through intra- and inter-Agency collaborations

FY19 Accomplishments:

- Cross-EPA Lead Mapping Coordination Workshop, May 2019
- Application of geospatial statistical methods and models to identify, map, and analyze locations of children's elevated blood lead levels (Census Tract scale) and associated sources of lead exposure to support lead mitigation efforts in states in Regions 1, 5, 6, and 7.
  - Region 1: Draft VT Pb maps to inform RRP discussions, per technical assistance request; delivered May 2019
  - Region 5: Invited presentations with draft maps for OH, MI, WI, MN, IL, IN for State partners; April 2019; May 2019; July 2019; September 2019

- Region 6: Draft maps for TX, LA, OK, AK for R6 meeting with State partners, per technical assistance request; delivered Sept 2019
- Region 7: Invited presentation with draft NE, KS, IA, MO results for Federal Pb Task Force meeting with Region 7 RA, HHS, HUD, per technical assistance request; delivered April 2019

OUTPUT: Methods and Data on Key Drivers of Blood Lead Levels in Children (SHC.5.2)

Data are needed to determine key drivers of blood lead levels from multimedia exposures, including the relative contributions to BLL from major sources and exposure pathways, to inform effective risk reduction strategies at national and local scales. These data are also needed to enhance and apply multimedia exposure modeling (i.e., the Integrated Exposure Uptake Biokinetic (IEUBK) model and All Ages Lead Model [AALM]) for regulatory determinations by reducing uncertainty, especially for the most at-risk groups, and for use in computing cleanup levels at Superfund and other contaminated sites. SHC will provide distributional (location specific) estimates of lead in soil, dust, drinking water, and food and will develop methods to estimate bioaccessibility of lead from soil and dust under different soil chemistry conditions and under different biological conditions. SHC will explore the best methodologies and approaches to obtain field data for soil and dust ingestion rates as a function of life stage, geographic factors, socioeconomic factors, and factors in the built environment. In conjunction with HHERA Output 2.1, SHC will develop innovative methods for evaluating exposure factors and assess impacts of risk management or mitigation actions on lead exposure risk or blood lead levels.

Products (Start date, planned delivery date):

Evaluate soil and lead mineralogy to aid in contaminated soil remediation technology development (FY2019, FY2021)

Human small intestine soil lead bioavailability model (FY2020, FY2021)

American Healthy Homes Study II: evaluate lead concentrations in drinking water, soils, and indoor house dusts and lead bioavailability in paired soil and indoor house dusts (FY2018, FY2023)

Health Effects of Changing Lead Exposures and Community Factors Which May Alter Potential Health Benefits (FY2020, FY2022)

Pilot study on communities with elevated children's BLLs to examine key drivers of exposure (FY2020, FY2023)

Methods and approaches to improve accuracy, reliability and confidence of children's soil and dust ingestion rates (FY2019, FY2022)

FY19 Accomplishments (hyperlinked to Appendix 1):

[HYPERLINK \l "_Long-Term_in_Situ_1"][HYPERLINK \l "_In_Vitro,_in"][HYPERLINK \l "_Estimating_relative_bioavailability"][HYPERLINK \l "_Systematic_review_and_1"]**From EPA Science Matters:** [HYPERLINK \l "_New_Testing_Method"]

Sustainable and Healthy Communities Research Program

Research Area: Site Characterization and Remediation (SHC.2)

OUTPUT: Methods, Tools, and Guidance on Remediation Options (SHC.2.1)

SHC will evaluate, develop, validate, and demonstrate remediation alternatives and tools to reduce risk, better assess sources and exposure at contaminated sites, and connect them quantitatively to biological and human health consequences. Potential products include: 1) methods and guidance for assessing contaminant bioavailability using passive sampling; 2) advancements in assessment tools for forecasting

residues in fish, shellfish, and wildlife; 3) improvements for addressing temporal and spatial variability associated with contaminant exposure; 4) demonstration studies to validate existing and newly developed assessment measures and tools; and 5) filling of key data gaps on chemicals of concern at contaminated sites, including reducing detection limits for priority contaminants.

Product (Start date, planned delivery date):

Assessment tools for heavy metal (Pb, As) bioavailability in sediments and soils (FY2019, FY2022)

FY19 Accomplishments (hyperlinked to Appendix)

- [HYPERLINK \l "_Point_of_Zero"]
- [HYPERLINK \l "_Dynamics_of_lead_1"][HYPERLINK \l "_Dynamics_of_lead"][HYPERLINK \l "_Relationship_between_Pb"][HYPERLINK \l "_Influence_of_Phosphate"]

[HYPERLINK \l "_Spatial_Distribution_of_1"][HYPERLINK \l "_Chapter_5_-"]

OUTPUT: Methods and Approaches to Improve Characterization of Heterogeneous Contaminant Sites (SHC.2.2)

Development of geochemical, geophysical, and modeling tools to support site characterization and the design of timely and cost-efficient groundwater remediation. This can include optimizing existing tools and designing new tools and approaches to define conceptual models at heterogeneous contaminant sites. Research may be based on numerical modeling simulations, laboratory experimentation, or field-based research.

PRODUCT (Start date, proposed delivery date):

Pb Isotopes as a Tool for Source Apportionment (FY2019, FY2022)

Sustainable and Healthy Communities Research Program

Research Area: Waste Recovery and Beneficial Use (SHC.8)

OUTPUT: Inventory and Assessment of Materials for Material Recovery and the Potential to Reduce Waste (SHC.8.1)

SHC will develop tools and methods to advance the use, reuse, and recycling of materials. This will enhance secondary materials markets and reduce barriers for material recovery. These research activities may include: 1) better characterizing and tracking the segments and economic activity of the deconstruction and building materials reuse sector and identifying data sources and gaps; 2) inventorying and evaluating specific commercial, residential, and industrial wastes of interest; 3) using buildings as material banks (e.g., repositories for useful construction material); and 4) inventorying harmful waste (such as solvents and foundry sands) that are not safe for reuse (e.g., lead based painted wood) and those that can be effectively processed for reuse to increase the value and capitalize these material sources. Various methods will be developed to inventory waste generated by industrial sectors.

Products:

Assessing the Opportunities and Challenges of Solar Panel Recycling for Sustainable End-of-Life Management (FY2020, FY2022)

An Examination of Factors with the Potential to Influence the Reduction/Elimination of Waste from Construction Projects (FY2020, FY2022)

OUTPUT: Technologies that Beneficially Reuse Waste Products (SHC.8.4)

SHC will evaluate, develop, test, and demonstrate technologies that beneficially reuse many types of waste such as industrial-use solvents and infrastructure waste (e.g., chat, foundry sands, coal combustion residue, slag). Any material use in these technologies will be tested for environmental impact in their testing scenarios. This research will produce practitioner-oriented tutorials on sustainable engineering technologies that can be used to enhance beneficial use policy and practices. SHC will collaborate with industrial partners through Cooperative Research and Development Agreements, where applicable.

Products (Start date, proposed delivery date):

Redirecting waste material streams for use as remedial soil amendments and engineering soil amendment mixtures to optimize in situ remediation of lead and other soil contaminants (FY2020, FY2022).

Use of Biochar in Dissolved and Particulate Metal Remediation and Monitoring in Water Streams (FY2021, FY2022)

FY19 Accomplishments (hyperlinked to Appendix):

[HYPERLINK \l "_Chapter_5_-_1"]

Regional Applied Research Effort

The [HYPERLINK "https://intranet.ord.epa.gov/regional-science/regional-applied-research-effort-rare"][2] (RARE) is an Office of Research and Development (ORD) program administered by the Office of Science Advisor, Policy & Engagement (OSAPE) that responds to the high-priority research needs of EPA Regions. RARE projects address a wide array of environmental science issues critical to ORD's regional partners. The Regional Science Liaisons (RSLs) manage the RARE process by fostering interactions and enhancing communication between the Regions and ORD laboratories and centers.

Projects (Start date - planned delivery date)[3]:

[HYPERLINK "https://intranet.ord.epa.gov/sites/default/files/2019-11/rare_2019_region_5_-_the_use_of_point-of-use_water_filtration_devices_for_lead.pdf"] (Region 5); Jan 2019 – Jan 2021

[HYPERLINK "https://intranet.ord.epa.gov/sites/default/files/2019-11/rare_2018_region_10_-_soil_amendments_to_reduce_bioavailability_of_toxic_metals_in_contaminated_soils_and_sediments.pdf"] (Region 10); Jan 2018 - Dec 2020

[HYPERLINK "https://intranet.ord.epa.gov/sites/default/files/2019-11/RARE%202015%20Region%206-%20Long-term%20fate%20evaluation%20of%20lead%20in%20phosphate%20treated%20waste%20materials%20that%20pass%20TCLP.pdf"] (Region 6); October 2015 – June 2020

Regional Superfund Technical Liaison Research Projects

The [HYPERLINK "https://intranet.ord.epa.gov/regional-science/superfund-and-technology-liaison-research-stlr-program"] (STLR) Program provides an opportunity for ORD and regional staff to collaborate on research that addresses high-priority, near-term, Superfund-related regional needs. Funded projects have taken many forms, including: applied research, conferences/workshops and trainings. The Superfund and Technology Liaisons (STLs) lead the program solicitation in their regions, assist in developing proposals and are substantially involved in the lifecycle of the projects.

Project (Start Date – Planned delivery date)[3]

[HYPERLINK "https://rsptracker.epa.gov/rsp/web/projects/2119"] (Region 8); July 2018 – September 2019

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[2] RARE and STLR descriptions are linked to EPA intranet sites for internal EPA access.
[3] Projects are linked to EPA intranet sites for internal EPA access.

Table 1: ORD's lead research products proposed for FY2020-FY2023.

This table is organized by ORD National Research Program and Research Area, Research Output, and product listing and includes listings for ORD's RAPID research tracking system and proposed starting and completion dates for each product.

RAPID System Listing	POC	ORD Center	Research Area / Output / Product	Initiation date (FY)	Proposed Delivery Date (FY)
			Health and Ecological Risk Assessment: Science Assessment Translation		
HERA.2.1			*Output: Technical Support to EPA Regions and states through the STSC and ERASC*		
	Kirrane	CPHEA	Evaluation of Health Impacts of Lead Remediation at ASARCO Superfund Site		2020
			Health and Ecological Risk Assessment: Essential Assessment and Infrastructure Tools		
HERA.4.1			*Output: Innovate, develop, and maintain a suite of essential software and support tools for risk assessment*		
	Brown	CPHEA	Support, evaluation, and review for lead biokinetic models		2021
SSWR.7	**Thurston**	**CESER**	**Safe and Sustainable Waters Research Program: Drinking Water and Water Distribution Systems (SSWR.7)**		
SSWR.7.20	Lytle	CESER	*Output: Resources and tools for characterizing and mitigating lead (Pb) and copper (Cu) release in drinking water distribution systems and premise plumbing*		
SSWR.7.20.1	Lytle	CESER	Treatment strategies for reducing lead and copper in drinking water	2020	2022
SSWR.7.20.2	Burkhardt	CESER	Lead exposure assessment and modeling tools	2020	2022
SSWR.7.20.3	DeSantis	CESER	Lead and copper source characterization and assessment strategies	2020	2022
SSWR.7.20.4	Triantafyllidou	CESER	Lead and copper sampling and monitoring tools	2020	04/2021 (FY2021)
SSWR.11	**Packard**	**OSAPE**	**Safe and Sustainable Waters Research Program: Technical Support**		
SSWR.11.31	Patterson	CESER	*OUTPUT: Technical support for water treatment, analytical methods, and risk assessments*		
SSWR.11.31.1, SSWR.11.31.2, SSWR.11.31.3	Tully	CESER	Technical support to EPA partners and communities to rapidly respond to high priority drinking water contaminant issues (Summary Reports: FY2020, FY2021, FY2022).	2020	2022

RAPID System Listing	POC	ORD Center	Research Area Output Product	Initiation date (FY)	Proposed Delivery Date (FY)
SHC.5	Cashdollar	CEMM	Sustainable and Healthy Communities Research Program: Chemicals of Immediate Concern: Lead		
SHC.5.1	Zartarian	CEMM	OUTPUT: Collaborative Science-Based Approaches and Results to Identify High Lead (Pb) Exposure Locations in the U.S. and Key Drivers at those Locations		
SHC.5.1.1	Zartarian	CPHEA	Development and application of methods for identifying high exposure lead (Pb) locations and the key drivers at those locations	2018	2021
SHC.5.1.2	Zartarian	CPHEA	Technical support to Regions to identify high lead exposure locations and key drivers in those locations	2020	2021
SHC.5.2	Stanek	CEMM	OUTPUT: Methods and Data on Key Drivers of Blood Lead Levels in Children		
SHC.5.2.1	Bradham	CEMM	Evaluate soil and lead mineralogy to aid in contaminated soil remediation technology development	2019	2021
SHC.5.2.2	Bradham	CEMM	Human small intestine soil lead bioavailability model	03/2020 (FY2020)	2021
SHC.5.2.3	Bradham	CEMM	American Healthy Homes Study II: evaluate lead concentrations in drinking water, soils, and indoor house dusts and lead bioavailability in paired soil and indoor house dusts	07/2019 (FY2019)	2023
SHC.5.2.4	Wyatt	CPHEA	Health Effects of Changing Lead Exposures and Community Factors Which May Alter Potential Health Benefits	12/2019 (FY2020)	2022
SHC.5.2.5	Stanek	CPHEA	Pilot study on communities with elevated children's BLLs to examine key drivers of exposure	2020	2023
SHC.5.2.6	Tulve	CEMM	Methods and approaches to improve accuracy, reliability and confidence of children's soil and dust ingestion rates	2018	2022
SHC.2	Holdsworth	CESER	Sustainable and Healthy Communities Research Program: Site Characterization and Remediation		
SHC.2.1	Burgess	CEMM	OUTPUT: Methods, Tools, and Guidance on Remediation Options		
SHC.2.1.13	Devereaux	CEMM	Assessment tools for heavy metal (Pb, As) bioavailability in sediments and soils	2019	2022
SHC.2.2	Wilkin	CESER	OUTPUT: Methods and Approaches to Improve Characterization of Heterogeneous Contaminant Sites		
SHC.2.2.4	Wilkin	CESER	Pb Isotopes as a Tool for Source Apportionment	2019	2022

RAPID System Listing	POC	ORD Center	Research Area Output Product	Initiation date (FY)	Proposed Delivery Date (FY)
SHC.8	Holdsworth	CESER	Sustainable and Healthy Communities Research Program: Waste Recovery and Beneficial Use		
SHC.8.1	Richardson	CESER	*OUTPUT: Inventory and Assessment of Materials for Material Recovery and the Potential to Reduce Waste*		
SHC.8.1.1	Demessie	CESER	Assessing the Opportunities and Challenges of Solar Panel Recycling for Sustainable End-of-Life Management	2020	2022
SHC.8.1.2	Richardson	CESER	An Examination of Factors with the Potential to Influence the Reduction/Elimination of Waste from Construction Projects	2020	2022
SHC.8.4	Al-Abed	CESER	*OUTPUT: Technologies that Beneficially Reuse Waste Products*		
SHC.8.4.2	Johnson	CPHEA	Redirecting waste material streams for use as remedial soil amendments and engineering soil amendment mixtures to optimize in situ remediation of lead and other soil contaminants	2020	2022
SHC.8.4.3	Al-Abed	CESER	Use of Biochar in Dissolved and Particulate Metal Remediation and Monitoring in Water Streams	2021	2022

Appendix 1: Annotated bibliography of FY19 ORD Lead Research

This Appendix contains citation information, links, and descriptions of peer-reviewed ORD lead research published in journals or presented to peer review panels. Other presentations or posters are available on request.

HERA: Essential Assessment and Infrastructure Tools

Estimates of Urinary Blood Lead Clearance and its Relationship to Glomerular Filtration Rate Based on a Large Population Survey

[HYPERLINK "https://www.ncbi.nlm.nih.gov/pubmed/?term=Diamond%20GL%5BAuthor%5D&cauthor=true&cauthor_uid=30983525"][1], [HYPERLINK "https://www.ncbi.nlm.nih.gov/pubmed/?term=Thayer%20WC%5BAuthor%5D&cauthor=true&cauthor_uid=30983525"][1], [HYPERLINK

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"https://www.ncbi.nlm.nih.gov/pubmed/?term=Klotzbach%20JM%5BAuthor%5D&cauthor=true&cauthor_uid=30983525"][1]. Estimates of urinary blood lead clearance and its relationship to glomerular filtration rate based on a large population survey. J Toxicol Environ Health A. 2019;82(5):379-382. DOI:[HYPERLINK "https://doi.org/10.1080/15287394.2019.1603280" \t "_blank"]

Product Description/Abstract:

Blood lead (Pb) clearance (CbPb) and serum creatinine clearance (CsCr), a metric of glomerular filtration rate (GFR), were estimated in approximately 7,600 subjects from the NHANES (2009-2016). Median CbPb in adults was 0.04 L/day (5th-95th percentile range: 0.01-0.12). Linear regression models explained approximately 68% of variance in CbPb in adults, with >98% of explained variance attributed to CsCr. These results provide an improved quantitative understanding of the possible effects of reverse causality in the interpretation of studies of associations between blood Pb and decrements in GFR.

POU Water Filters Effectively Reduce Lead in Drinking Water: A Demonstration Field Study in Flint, Michigan

Bosscher, V., D. Lytle, M. Schock, A. Porter, AND M. Deltoral. POU Water Filters Effectively Reduce Lead in Drinking Water: A Demonstration Field Study in Flint, Michigan. JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH, PART A. Taylor & Francis Group, London, Uk, 54(5):484-493, (2019). [HYPERLINK "https://doi.org/10.1080/10934529.2019.1611141"]

Impact/Purpose Statement:

Water sampling data from this study indicates that POU filters are a reliable method to reduce both soluble and particulate lead (well above 150 µg/L) down to low levels. Over 97% of filtered water samples contained lead below 0.5 µg/L, and the maximum lead concentration in filtered water was 2.9 µg/L, well below the bottled water standard. POU water filters can be an important and reliable barrier against unpredictable lead release from LSLs and plumbing materials. This study shows that POU water filters can be an important and reliable barrier against unpredictable lead release from LSLs and plumbing materials. The effectiveness of the POU activated carbon block filters in reducing lead concentrations, even above the 150 µg/L NSF/ANSI-53 challenge standard, is likely related to trapping particles due to the small effective pore size of the filters, in addition to absorption of soluble lead. Properly installed and maintained POU filters, certified under both NSF/ANSI-53 (for total lead) and NSF/ANSI-42 (for fine particulate), can protect all populations, including pregnant women and children, by reducing lead in drinking water to levels that not would result in a significant increase in overall lead exposure.

Product Description/Abstract:

A field study was conducted to test the effectiveness of faucet-mounted point of use (POU) water filters for removing high concentrations of lead that can occur in drinking water due to plumbing sources including lead service lines (LSL). These filters were concurrently certified for total lead removal under NSF/ANSI Standard 53 (NSF/ANSI-53) and for fine particulate (Class I) reduction under NSF/ANSI Standard 42 (NSF/ANSI-42). In 2016, filtered and unfiltered drinking water samples were collected at over 345 locations in Flint, Michigan. Water sampling data indicates that POU filters are a reliable method to reduce both soluble and particulate lead (well above 150 µg/L) down to low levels. Over 97% of filtered water samples contained lead below 0.5 µg/L, and the maximum lead concentration in filtered water was 2.9 µg/L, well below the bottled water standard. POU water filters can be an important and reliable barrier against unpredictable sporadic lead release from LSLs and plumbing materials. The effectiveness of the POU activated carbon block filters in reducing lead concentrations, even above the 150 µg/L NSF/ANSI-53 challenge standard, is likely related to trapping particles due to the small effective pore size of the filters, in addition to absorption of soluble lead. Properly installed and maintained POU filters, certified under both NSF/ANSI-53 (for total lead) and NSF/ANSI-42 (for fine particulate), can protect all populations, including pregnant women and children, by reducing lead in drinking water to levels that not would result in a significant increase in overall lead exposure

Impact/Purpose Statement:

This manuscript aims to inform the scientific community of the observational research conducted at the US EPA's AMSARC lab on galvanic lead corrosion, based on the first and only collection of actual excavated lead galvanic joints in North America. The specific goal of this work was to employ comprehensive visual and mineralogical characterization of pipe scales at galvanically connected lead-brass or lead-copper joints, excavated from different U.S. water distribution systems after long periods of service, in order to: (1) directly confirm the presence or absence of galvanic corrosion, (2) conclusively determine identify which metal in the galvanic cell actually behaved anodically (i.e., corroded) over time, and (3) evaluate identify mineral phases at the galvanic junction as opposed to the remaining pipe surface, to gain mechanistic insights on possible galvanic microlayer effects and associated implications.

Product Description/Abstract:

The importance/longevity of galvanic corrosion as a mechanism of toxic lead release into drinking water has been under scientific debate in the U.S. for over 30 years. Visual and mineralogical analysis of 28 lead pipe joints, excavated after 60+ years from 8 U.S. water utilities, provided the first direct view of galvanic corrosion presence/extent in practice. Three patterns were observed: (1) no galvanic corrosion; (2) galvanic corrosion with lead pipe cathodic; (3) galvanic corrosion with lead pipe anodic. Pattern 3 is consistent with the order of increasing nobility found in empirical galvanic series (lead, brass, copper) and poses the greatest risk of Pb exposure. Pattern 2 is consistent with galvanic battery reversion, and was identified in water systems with well-developed Pb(IV) scales on their lead pipes. A variety of copper-sulfate minerals (Pattern 2), and lead-sulfate and/ lead-chloride minerals (Pattern 3) were identified in the galvanic zones, illustrating the migration of chloride and sulfate ions toward the sacrificial anode. Geochemical modeling confirmed the required pH drop from the bulk water level to pH 3.0-4.0 (Pattern 2) and pH<5.5 (Pattern 3) in order to form the identified minerals. Despite joints being over 60 years old, galvanic zones in Pattern 3 were active and possibly posed an important source of lead to drinking water.

Impact Statement

Eliminating the sources of lead exposure from the environment is an ongoing public health goal. Lead is a neurotoxin that can cause permanent cognitive and behavioral impairments in children, and cardiovascular and kidney problems in adults. This study summarizes the results of sequential sampling for lead in Flint, Michigan. This project is a part of the efforts under Safe and Sustainable Water Resources research for distribution system corrosion analysis and modeling research (SSWR 6.01C)

Background

As part of the response to Flint, Michigan's drinking water lead disaster, a return to their original drinking water source (Lake Huron) and an increase in orthophosphate dose was implemented in late 2015. In 2016, EPA performed multiple rounds of sequential or "profiling" water sampling to evaluate corrosion control effectiveness and identify lead sources in homes and service lines, as well as to evaluate the effectiveness of corrosion control treatment with time on the different plumbing components.

Study Description

Sequential drinking water sampling was conducted at single-family residences in four rounds using comparable protocols in Flint, MI, between January 28, 2016 and November 15, 2016. EPA field sampling coordinators collected samples, maintained field sampling records, and shipped properly preserved samples under chain-of-custody to an EPA regional laboratory. EPA regional laboratory personnel received samples under chain-of-custody and analyzed them for total metals and other water quality parameters based on EPA drinking water methods.

Results

The results showed that lead levels, including high lead levels likely associated with particles, decreased with time in homes sampled during the 11-month evaluation period. Although sequential sampling indicated that brass fittings, brass fixtures, and galvanized pipes were lead sources, LSLs were the greatest source of lead when present.

Conclusion

Sequential sampling was an effective way to identify lead sources and track the progress of corrosion control with time. The removal of LSLs reduced the total mass of lead contributed to the drinking water on average by 86%; more significant reductions would be expected by implementing additional precautions during LSL removal and if no galvanized plumbing is present in the home.

Impact Statement

This study summarizes the results of a pipe scale study that compared the observed and the predicted phases of compound and elemental compositions of pipes. This study proved that for many systems, appropriate water sampling is needed to determine actual lead release from lead service lines and that pilot studies would usually be necessary to evaluate and optimize corrosion control alternatives. This project is a part of the efforts under Safe and Sustainable Water Resources research for distribution system corrosion analysis and modeling research (SSWR 6.01C).

Background

Since 1991, after the publication of the US Environmental Protection Agency's (EPA) lead and copper rule (LCR), public water systems (PWSs) have been required to monitor and control lead release within their distribution systems. PWSs use solubility models as guidance to see which mineral phases are predicted to control lead release. In some systems, these computations have been accurate in predicting lead release, however, there are still many uncertainties and potential errors in the simulations.

Study Description

Lead service line scales from 22 drinking water distribution systems in EPA's Region 5 were evaluated. The pipe scale analysis used multiple analytical methods for compound and elemental composition to compare the observed phases to those predicted by solubility modeling.

Results

This study found that only 9 out of 22 of the systems samples had lead service line scales that followed the model predictions. Nine of the systems contained unpredictable amorphous phases of unknown lead release characteristics at the scale surface.

Conclusion

This study concluded that for many systems, appropriate water sampling is needed to determine lead release from LSLs, and pilot studies would usually be necessary to evaluate and optimize corrosion control alternatives.

Impact Statement

This report summarizes the construction and use of pipe rigs to optimize corrosion control treatment and evaluation in Flint, Michigan. The study proved the usefulness of using a pipe rig system to provide critical assessment of corrosion control performance. This project is a part of the efforts under Safe and Sustainable Water Resources research to support water treatment in achieving regulatory compliance (SSWR 6.01C).

Background

In 2015, Flint suffered from an extreme loss of corrosion control and elevated lead release due to a change in their major source water and water treatment. During the onset of these events, the United Stated Environmental Protection Agency provided recommendations for studies that would develop a detailed assessment of problematic lead release sources, corrosion control optimization studies for the immediate future with Detroit water, and any other potential future changes. In order to prepare the City of Flint's for any future potential changes, EPA's Office of Research and Development's Drinking Water Treatment and Distribution Branch designed, fabricated, and installed four pipe rigs in Flint.

Study Description

Four pipe rigs were constructed utilizing lead service lines (LSL) that were removed from service within the Flint water system. These rigs were operated on a cycle that was intended to simulate periodic water demand in a typical household of four residents. Treatment chemicals, such as orthophosphate, were fed into the system to determine their success at corrosion control. Additionally, influent and stagnant water quality samples were taken periodically to check the levels of lead in the system.

Results

A comparison between the lead levels from the rigs and from the sequential sampling in a Flint home with a LSL would improve confidence in the rigs and in the overall value of using pipe rigs to assess and improve corrosion control.

Conclusion

This study shows the usefulness of pipe rig systems with automated operation to provide a critical tool for assessment of current corrosion control performance after stabilization and verification against actual field sampling data for lead pipes in homes.

Long-Term in Situ Reduction in Soil Lead Bioavailability Measured in a Mouse Model

Impact/Purpose Statement:

Contaminated site remedial currently involves soil removal and replacement with clean topsoil, which is expensive and difficult at contaminated sites. Adding soil amendments that combine with lead in soil so that the human body cannot absorb the lead can be a cost-effective way to reduce human health risks associated with continued presence of contaminants. This research showed that the addition of phosphate and iron to contaminated soil significantly reduced soil lead bioavailability 16 years after the original soil treatment. This assessment used a low cost, rapid bioavailability method developed and validated by EPA to produce these results.

Product Description/Abstract:

Effects of different treatments on the bioavailability of lead (Pb) in soil from a smelter emission contaminated site in Joplin, Missouri, were evaluated in a mouse model. Similar estimates of relative bioavailability for Pb in untreated or treated soil were obtained in mice and in the well-established juvenile swine model. In the mouse model, treatments that used phosphate (phosphoric acid or triple superphosphate) combined with iron oxide or biosolids compost significantly reduced soil Pb bioavailability. Notably, effects of these remediation procedures were persistent, given that up to 16 years had elapsed between soil treatment and sample collection. Remediation of soils was associated with changes in Pb species present in soil. Differences in Pb species in ingested soil and in feces from treated mice indicated that changes in Pb speciation occurred during transit through the gastrointestinal tract. Use of the mouse model facilitates evaluation of remediation procedures and allows monitoring of the performance of procedures under laboratory and field conditions.

Impact/Purpose Statement:

Sustainable in situ remediation technologies are a high priority research need for OLEM and Regional offices due to the high cost of soil removal/disposal and the large number of contaminated sites across the United States. Determination of the influence of P in the diet on Pb bioavailability in the mouse provides insight into the design of more effective soil-specific remediation processes. Differences in Pb species between diet and feces indicated that transformation of Pb species can occur during gastrointestinal tract transit. These interactions between Pb and P that alter Pb speciation may be important determinants of the bioavailability of Pb ingested in soil. Understanding linkages between alterations in Pb speciation in remediated soils and changes in Pb bioavailability will benefit public health by improving the effectiveness of soil remediation strategies.

Product Description/Abstract:

Effects of dietary P level on the oral bioavailability of Pb present in soil were examined in a mouse model. Adult female C57BL/6 mice had free access to AIN-93G purified rodent diet amended with Pb as a soluble salt, Pb acetate, or in a soil matrix (NIST SRM 2710a). Diets used in these studies contained P at a nutritionally sufficient level (0.3% w/w) or at a higher (1.2%) or a lower level (0.15%). For either dietary Pb source (Pb acetate or NIST SRM 2710a), low dietary P level markedly increased accumulation of Pb in bone, blood, and kidney. Tissue Pb levels in mice fed a high P in diet were not different from mice fed the basal P diet. Dietary P and Pb interacted to affect body weight change and feed efficiency in mice. The relative contribution of different Pb species in diet and feces was also affected by dietary P level. Differences in Pb species between diet and feces indicated that transformation of Pb species can occur during gastrointestinal tract transit. These interactions between Pb and P that alter Pb speciation may be important determinants of the bioavailability of Pb ingested in soil.

Methodological factors influencing inhalation bioaccessibility of metal(loid)s in PM$_{2.5}$ using simulated lung fluid

Background/Overview

In this study, methodological factors influencing the dissolution of metal(loid)s in simulated lung fluid (SLF) were assessed in order to develop a conservative method for the assessment of inhalation bioaccessibility in PM2.5. To achieve this aim, the effects of solid to liquid (S/L) ratio (1:100 to 1:5000), agitation (no agitation, occasional shaking, orbital and end-over-end rotation), composition of SLF (artificial lysosomal fluid: ALF; phagolysosomal simulant fluid: PSF) and extraction time (1 to 120 h) on metal(loid) bioaccessibility were investigated using PM2.5 from three Australian mining/smelting impacted soils and a certified reference material. The results highlighted that SLF composition significantly ($p < 0.001$) influenced metal(loid) bioaccessibility and that when a S/L ratio of 1:5000 and end-over-end rotation was used, metal(loid) solubility plateaued after approximately 24 h. Using the methodological parameters that yielded the most conservative estimate of metal(loid) bioaccessibility, PM2.5 was then subjected to simulated gastro-intestinal tract (GIT) solutions to simulate lung clearance and swallowing and the results were compared to extraction using SLF alone. Although metal(loid) bioaccessibility in SLF alone (24 h) varied from simulated GIT solutions alone ($p < 0.05$), there was no significant difference ($p > 0.05$) when SLF alone (24 h) was compared to SLF followed by simulated GIT solutions.

Systematic review and meta-analyses of lead (Pb) concentrations in environmental media (soil, dust, water, food, and air) reported in the United States from 1996 to 2016

Impact/Purpose Statement:

The objective of this manuscript is to report the systematic review and meta-analyses undertaken in support of U.S. EPA's Pb exposure-dose modeling effort. A database was created that included Pb concentration data for multiple environmental media (air, soil, dust, water, and food) and associated sample collection characteristics for samples collected in the United States from 1996 - 2016 and published in peer-reviewed and grey articles. Random effects models were run on subgroups that shared similar sample collection characteristics (e.g., residential, community gardens, Pb Superfund, benchmark, first draw) to generate single group mean summaries. The results from the random effects meta-analyses were then compared to data from national surveys. Finally, sensitivity analyses were conducted by running the meta-analyses on the combined national survey and literature datasets.

Product Description/Abstract:

Environmental lead (Pb) contamination is a persistent public health issue that prominently impacts communities across the United States. Multimedia Pb exposure assessments are utilized to provide a holistic evaluation of Pb exposure and inform the development of programs and regulations that are protective of human health. To conduct multimedia exposure assessments, robust, media-specific environmental Pb concentration data are necessary. To support this effort, systematic review and meta-analysis methods were used to conduct a comprehensive synthesis of research measuring Pb in multiple environmental media (soil, dust, water, food, and air) over a 20-year period within the United States. The breadth of the resulting database allowed for the evaluation of sample characteristics that can serve as indicators of environmental Pb contamination. Random effects models run on literature and national survey datasets generated overall mean estimates of Pb concentrations that can be used for multimedia Pb exposure modeling for general and high-exposure-risk populations. Results from our study highlighted several important trends: 1) The mean estimate of Pb in residential soils is three times higher for urbanized areas than non-urbanized areas; 2) The mean estimate of Pb in produce reported in the literature is approximately three orders of magnitude greater than commercially-sourced raw produce monitored in national surveys; 3) The mean estimate of Pb in soils from shooting ranges is two times greater than non-residential Pb contaminated Superfund sites reported in the literature; 4) Research reporting environmental Pb concentrations for school and daycare sites is very limited; 5) Inconsistent sample collection and reporting of results limited synthesis efforts; and 6) The U.S. EPA's Air Quality System was the most robust, publicly available national survey resource. Results from these analyses will inform future multimedia Pb exposure assessments and be useful in prioritizing future research and program development.

Point of Zero Charge: Role in Pyromorphite Formation and Bioaccessibility of Lead and Arsenic in Phosphate-Amended Soils

Impact/Purpose Statement:
The pH at which the sorbent surface charge takes a zero value is defined as point of zero charge (pHPZC). At this pH, the sum charge of the positive surface sites is equal to that of the negative ones, resulting in a high state of entropy and disequilibrium. The knowledge of pHPZC helps to hypothesize on the ionization of functional groups and their interaction with metal species in solution. At solution pHs higher than pHPZC, sorbent surface is negatively charged and could interact with positively charged metal species while at pHs lower than pHPZC, solid surface is positively charged and could interact with negative species [19]. We theorized that driving the pH of a soil system to a state of disequilibrium may enhance contaminant immobilization. An essential aspect of in-situ immobilization of Pb via phosphate amendments is to lower the risk (bioavailability) of Pb in soil. Bioavailability can be assessed with animal (in-vivo) and simple chemical extraction assays (in-vitro). In this study, EPA Method 1340 was utilized as the in vitro bioaccessibility assay (IVBA), which includes pH 1.5 as the standard pH for extracting in vitro bioaccessible Pb and As in order to account the maximum absorption during fasting condition. As stated in Method 1340, the assay at pH 1.5 is not suitable for phosphate amended soils, which overestimates Pb bioaccessibility in amended soils. However, several reports have found less variability at pH 2.5 compared to pH 1.5. The difference in Pb extractability at pH 1.5 versus pH 2.5 for phosphate amended soils may be due to change in phosphate chemistry. Below pH 2.12, phosphate prefers to be H_3PO_4, and above pH 2.12 phosphate prefers $H_2PO_4^{-1}$. A slight shift in extraction pH can have a profound effect on phosphate chemistry and extractability. Therefore, IVBA using pH 2.5 rather than 1.5 has potential to more accurately measure efficacy of phosphate soil amendments to reduce bioaccessible Pb [6,24,25]. This study conducted the IVBA extraction at both pH 1.5 and pH 2.5 following the standard IVBA procedure. The objective of this study was to compare the combined effect of pH with respect to PZC and different rates of phosphate application on the formation and stability of pyromorphite over time, and on Pb and As bioaccessibility as impacted by speciation changes. Attempts have been made to fine-tune and understand the limitations of Pb conversion to pyromorphite in phosphate amended soils.

Product Description/Abstract:

Soluble lead (Pb) can be immobilized in pure systems as pyromorphite through the addition of phosphorus (P) sources; however, uncertainties remain in natural systems. Knowledge of point zero charge (PZC) is important to predict the ionization of functional groups and their interaction with metal species in solution. This study utilized Pb- and As-contaminated soils to determine the combined effect of pH with respect to PZC and different rates of P-application on pyromorphite formation as well as Pb and arsenic (As) bioaccessibility as impacted by speciation changes. Solution chemistry analysis along with synchrotron-based Pb- and As-speciation as well as bioaccessibility treatment effect ratios (TERs) were conducted. Results indicated no significant effect of PZC on pyromorphite formation in P-amended soils; however, the TERPb appeared significantly lower at pH > pHPZC and higher at pH pHPZC compared to the other two treatments for the tested soils.

In Vitro, in Vivo, and Spectroscopic Assessment of Lead Exposure Reduction via Ingestion and Inhalation Pathways Using Phosphate and Iron Amendments

Impact/Purpose Statement:

Two significant pathways for Pb exposure in humans are incidental ingestion of soil or surface dust and inhalation of re-suspended dust or airborne particulate matter with <10 µm in aerodynamic diameter (PM10). Following the ingestion of soil and surface dust, Pb may be solubilized in the acidic conditions of the stomach (pH 1.5-2.5) and subsequently absorbed by the small intestine (pH 7). Similarly, upon inhalation of re-suspended dust, Pb may be solubilized in the surfactants and epithelial lining fluid (pH 7.4) of the lungs. Solubilized Pb may be rapidly absorbed via the air blood barrier into the systemic circulation. Reduction in Pb bioavailability (Pb absorption into the systemic circulation) using soil amendments (e.g. phosphates, metal oxides, clay minerals) has been argued to be a cost effective risk minimization strategy. This study compared lead (Pb) immobilization efficacies in mining/smelting impacted soil using phosphate and iron amendments via ingestion and inhalation pathways using in vitro and in vivo assays, in conjunction with investigating the dynamics of dust particles in the lungs and gastro-intestinal tract via X-ray fluorescence (XRF) microscopy. Pb impacted soil from Broken-Hill (Australia) was treated with soil amendments with Pb bioaccessibility and bioavailability assessed in ingestible and inhalable fractions. Pb bioavailability was significantly reduced ($p < 0.05$) by phosphate amendments in the inhalable (56.4% reduction) and ingestible (21.1% reduction) particle fractions.

Dynamics of lead bioavailability, speciation and spectroscopic investigation of the link between ingestion and inhalation pathways

Kastury, F., E. Smith, E. Lombi, M. Donnelley, P. Cmielewski, D. Parsons, M. Noerpel, Kirk G. Scheckel, A. Kingston, G. Myers, D. Paterson, M. de Jonge, AND A. Juhasz. Dynamics of Lead Bioavailability and Speciation in Indoor Dust and X-ray Spectroscopic Investigation of the Link between Ingestion and Inhalation Pathways. ENVIRONMENTAL SCIENCE & TECHNOLOGY. American Chemical Society, Washington, DC, 53(19):11486-11495, (2019). [HYPERLINK "https://doi.org/10.1021/acs.est.9b03249"]

Impact/Purpose:

Exposure to lead (Pb) presents social, economic and environmental burden on families, communities and society as a whole. When inhaled, Pb particles may have prolonged lung residence time, potentially causing chronic toxicity and neurological impairment in children. However, absorption of Pb via the inhalation of Pb contaminated dust is not well studied. This study investigated the uptake of Pb into blood from indoor dust, clearance of particles from the lungs to the gastro-intestinal tract, and the influence of mineralogy on Pb absorption and particle retention. This study lends fundamental insight to our knowledge of Pb exposure from dust via the inhalation pathway and identifies X-ray based spectroscopy as a valuable tool for future research into metal exposure assessment. Pb bioavailability and retention/clearance with mining/smelting impacted dust, and the link between Pb inhalation and ingestion scenarios are currently not well understood. Consequently, this study investigated the dynamics of Pb absorption from Pb contaminated house dust following instillation into C57BL/6 mouse lungs. Changes in blood Pb concentration were monitored over a 24 h exposure period. X-ray Fluorescence (XRF) microscopy of whole organs was then utilized to visualize particle distribution and clearance from the lungs into the GI tract. Changes in Pb speciation in vivo were also assessed using X-ray Absorption Near Edge Spectroscopy (XANES).

Product Description/Abstract:

Lead (Pb) exposure from household dust is a major childhood health concern because of its adverse impact on cognitive development. This study investigated the absorption kinetics of Pb from indoor dust following a single dose instillation into C57BL/6 mice. Blood Pb concentration (PbB) was assessed over 24 h, and the dynamics of particles in the lung and gastro-intestinal (GI) tract were visualized using X-ray fluorescence (XRF) microscopy. The influence of mineralogy on Pb absorption and particle retention was investigated using X-ray absorption near-edge structure spectroscopy. A rapid rise in PbB was observed between 0.25 and 4 h after instillation, peaking at 8 h and slowly declining during a period of 24 h. Following clearance from the lungs, Pb particles were detected in the stomach and small intestine at 4 and 8 h, respectively. Analysis of Pb mineralogy in the residual particles in tissues at 8 h showed that mineral-sorbed Pb and Pb-phosphates dominated the lung, while organic-bound Pb and galena were the main phases in the small intestines. This is the first study to visualize Pb dynamics in the lung and GI tract using XRF microscopy and link the inhalation and ingestion pathways for metal exposure assessment from dust.

Background/Overview

Lead (Pb) exposure from incidental soil ingestion is a significant global concern due to its negative impact on neurological and cognitive development in children. Pb immobilization via phosphate treatment is an in-situ remediation strategy that has been documented to reduce Pb exposure in humans, swine, minipig, rats and mice. Phosphate amendments may promote the formation of Pb-phosphate species (e.g. pyromorphites and tertiary Pb phosphates), which exhibit low solubility in the acidic conditions of the stomach, thereby limiting absorption in the small intestines. It has also been suggested that if Pb-phosphates are not formed in-situ, they may form in-vivo following solubilization of Pb and phosphate in the stomach and reaction in the small intestines.

In this study, an in-vitro-in-vivo-correlation (IVIVC) between Pb bioaccessibility (IVBA) and Pb relative bioavailability (RBA) was assessed to determine whether the efficacy of Pb immobilization in phosphate amended soils could be predicted using an in-vitro approach. In order to achieve this aim, mining/smelting impacted soil from Broken Hill was treated with phosphate and the Pb RBA and IVBA were assessed. These data, in conjunction with data from Juhasz et al., were used in linear regression models to investigate if a predictive relationship exists between Pb RBA and IVBA for assessing the efficacy of phosphate amended soils. This research highlights the complexities associated with the prediction of Pb RBA in phosphate amended soil.

Description:

In this study, an in vitro in vivo correlation (IVIVC) between Pb in vitro bioaccessibility (IVBA) and relative bioavailability (RBA) was explored to determine whether the efficacy of Pb immobilization in phosphate amended soils could be predicted using an in vitro approach. Mining/smelting impacted soil from Broken Hill, Australia (582–3536 mg/kg of Pb in the 1000 mg/kg Pb while treatment effect ratios of 0.89–0.99 (SBRC-G), 0.09–0.71 (SBRC-I) and 0.27–0.80 (RBA) were observed in PA amended soil (Pb:P = 1:5). Although significant ($p < 0.05$) correlation were obtained between Pb RBA and IVBA (%) determined using SBRC-G ($r = 0.64$) and SBRC-I ($r = 0.67$), the strengths of the relationships were weak ($r2 = 0.41–0.45$). This research highlights the complexities associated with the prediction of Pb RBA in phosphate amended soil.

Influence of Phosphate Amendment and Zinc Foliar Application on Heavy Metal Accumulation in Wheat and on Soil Extractability Impacted by a Lead-Smelter Near Jiyuan, China

Impact/Purpose:

Heavy metals are the most widespread pollutants in the environment, and can be readily absorbed by plants and animals, allowing entry into the food chain and exerting negative effects on human health. Nonferrous metal mining and smelting are major sources of heavy metal contamination in the environment. During the mining and smelting process of nonferrous metals, heavy metals enter the environment through the weathering and leaching of solid wastes, emission of polluted water, or the atmospheric decomposition of particles from stacks of the smelters. China is the biggest lead (Pb) producer in the world at present. Lead mining and smelting have resulted in accumulation of lead and cadmium (Cd) in soils in many areas of some provinces, such as Henan, Hunan and Guangdong. Heavy metal pollution near smelting facilities has resulted in elevated concentrations of Pb and Cd in crop grains, bearing negative impacts on the health of local residents from the heavy metals. Jiyuan City in Henan Province in northern China produces about 800,000 tonnes of Pb annually, which is about 10% of the world annual Pb output. High blood lead levels have been found for children living near the smelters. Ingestion of heavy metal polluted food and water is one of the dominant pathways for accumulation in humans living near polluted areas. This field study was conducted in a smelter impacted area in Jiyuan, China to investigate, i) the effect of whole and split application of phosphate amendments on Pb and Cd availability in soil and the accumulation of Pb and Cd in wheat grains; and ii) the effect of foliar application of Zn to wheat plants on the accumulation of Cd in wheat grains.

Description: Higher concentrations of Pb and Cd in wheat grains harvested in several lead-smelting-polluted areas in northern China have been reported. This field experiment was conducted to investigate the effect of phosphate amendment and Zn foliar application on the accumulation of Pb and Cd in wheat grains grown in a lead-smelting impacted area in Jiyuan in northern China. The soil (total Pb and Cd are 261 and 2.65 mg kg^{-1}, respectively) was amended with superphosphate at P:Pb ratios (mol:mol) of 1.90 or 2.57 either during wheat (Triticum aestivum L.) planting or a split of 60% of the phosphate applied at planting, with remaining 40% applied at the jointing stage. Zn was sprayed on the canopy of the wheat plants at the jointing stage. The phosphate amendment resulted in lower DTPA (diethylene triamine pentaacetic acid)-extractable Pb (1.39–10.7% lower than the control) and Cd (0.040–7.12%) in the soil. No significant effect of split application of phosphate was found on Pb and Cd availability in soil; however, higher rates of P resulted in lower Pb and Cd availabilities in the soil. Grain Pb (5.41–21.5% lower than the control), Cd (3.62–6.76%), and Zn (4.29–9.02%) concentrations were negatively affected by the phosphate application, with higher rates of phosphate resulting in lower grain heavy metal concentrations. Foliar application had no statistically significant influence on Pb and Cd concentrations in the grain ($p > 0.05$). Although Pb and Cd concentrations in wheat grains were reduced by the phosphate application, their concentrations were still much higher than the maximum permissible concentrations for wheat in the national standards of China.

Impact/Purpose:

Heavy metal accumulation in soil has attracted increased attention recently from residents to regulators in China. According to the bulletin of Ministry of Environmental Protection and Ministry of Land Resources (2014), 16.1% of the land in China is polluted, with Cd, Hg, As, Cu and Pb ranked as priorities in the pollutant list. In China, heavy metal pollution in soil poses a more serious risk to the health of local inhabitants than in most other countries, due to the low farmland area per capita in the polluted areas and the short distance between smelters and resident communities, which is true for many smelters in China. For source identification of heavy metals in soil, Pb isotopic analysis has been successfully utilized. Recently, Bi et al (2006) applied elemental correlation of the ratios between Cd and Pb in contaminated soils to discriminate the pollution from atmospheric deposition and that from solid waste of Zn smelting. They concluded that because of the lower boiling point of Cd than those of Pb and Zn, Cd will accumulate in particulate matters while Pb and Zn tend to accumulate in solid waste during the smelting process. Shen et al (2017) demonstrated that pollution of soil samples from different sampling sites with similar Cd/Pb ratios was distinguishable to identify the source. Non-linear correlation between Cd, Pb concentrations of soil samples to the distance of the smelters have been noticed in different works, due to the deposition characteristics of the particulate matters from the stack. Thus, if a soil is affected by pollution sources from more than one lead smelting stack, the correlation may very likely to change. As a result, it is possible to discriminate pollution sources of heavy metals in soils within an area predominantly affected by atmospheric deposition from a smelter. The purpose of the work was to, i) investigate the distribution of heavy metals in soils in the vicinity of lead smelters by sampling a larger area than the previously reported studies in Jiyuan, and ii) use the distribution of heavy metals in soils to estimate the contribution of different sources on the accumulation of heavy metals in soils near a lead smelter.

Description:

This work was conducted to explore heavy metal pollution in soils in an area near lead smelters in Jiyuan City, which is one of the main lead production areas in China. Altogether, 88 topsoil samples (0–20 cm) were collected from farmlands near the Yuguang lead smelting facilities; the sampling sites were 1570 to 6388 m to the main stack of the Yuguang. Analysis of the samples indicated that (i) the ranges of total Cd and Pb concentrations were 0.81–4.30 and 64.5–435 mg kg−1, respectively, mean pollution indices (concentration in soil/background value, PI) were 32.8 and 9.11, respectively, and the concentrations of total Cu, Zn, and Ni were slightly higher than the background values. Mean concentrations of DTPA-extractable Cd and Pb were 0.752 and 58.7 mg kg−1, respectively. (ii) The total concentrations of Cd, Pb and Pb/Cd ratios of samples decreased as the distance to the main stack of the Yuguang increased. Abnormal variations of these trends suggested these parameters of certain samples were affected by pollution sources other than the Yuguang. (iii) Judged by the results of this work, the area of the heavy metal-polluted land in Jiyuan was much greater than 115 km2, a value reported by an earlier investigation. These results indicate that the soil in the study area was polluted by Cd and Pb emissions from more than one polluting sources, the variation of Cd, Pb concentration and Pb/Cd ratios of samples to the distance of the pollution source can be potentially used for pollution source identification.

George, SE, Wan, Y. (2019). Advances in characterizing microbial community change and resistance upon exposure to lead contamination: Implications for ecological risk assessment, Critical Reviews in Environmental Science and Technology, https://doi.org/10.1080/10643389.2019.1698260

Background/Overview:

Environmental and occupational lead exposure continues to cause health effects globally. Unlike some other metals, lead is not biologically essential. Microorganisms play an important role in lead biogeochemistry and bioavailability. Once exposed to lead contamination, some microorganisms develop a variety of resistance mechanisms that are selective in high lead concentration areas, resulting in an increase in lead resistance genes and changes in microbial community activity and composition. The objective of this work is to provide a critical review of recent research on the impact of lead contamination on microbial community structure and function as well as lead resistance mechanisms and their use for lead biosensor development for potential application in bioavailability assessment of contaminated sites. The specific objectives are as follows: 1) to evaluate the impact of lead contamination on microbial community structure and function in contaminated terrestrial soils and aquatic sediments; 2) to elucidate various lead resistance mechanisms; and 3) to leverage resistance genes for lead biosensor development to detect lead and assess lead bioavailability.

Chapter 5 - Biochar for Mine Land Reclamation

Ippolito, J., L. Cui, J. Novak, AND Mark G Johnson. Chapter 5 - Biochar for Mine Land Reclamation. Biochar from Biomass and Waste: Fundamentals and Applications. Elsevier Inc, Waltham, MA, , 75-90, (2019). [HYPERLINK "https://doi.org/10.1016/B978-0-12-811729-3.00005-4"]

The number of abandoned mines globally is in the hundreds of thousands, with many mines capable of generating acidity, increasing metal solubility, and degrading environmental quality. Biochar may play a role in alleviating acidity and heavy metal contamination by increasing soil pH and increasing binding sites for chemical reactions to occur. Specifically, biochar can sequester heavy metals through various reactions, including precipitation or bound to organic and inorganic phases. Subsequently, plant growth conditions may be improved and abandoned mine site reclamation may become successful via biochar application. It is important to identify the heavy metals of concern (e.g., Cd, Cu, Pb, Zn), and the correct biochar application rate for their sequestration. This chapter reviews the recent literature with respect to biochar use for sequestering heavy metals from water and soils. It is anticipated that this will guide the reader to better understand the role biochar may play in mine land reclamation scenarios.

Appendix 2: Stories from EPA Science Matters

[HYPERLINK "https://www.epa.gov/sciencematters/reducing-childrens-lead-exposure-omaha-nebraska"]

Published August 13, 2018

For over 125 years, the American Smelting and Refining Company operated a lead refinery in Omaha, Nebraska, only a few blocks west of the Missouri River. Large amounts of lead were emitted into the air, contaminating the surrounding neighborhoods. Between 1998 and December 2015, EPA sampled more than 40,000 residences in the area, and found that about thirty-three percent of the properties had soil in their yards with lead above the cleanup level.

EPA's Region 7, which encompasses a four-state area including Nebraska, has been working for years to clean up the neighborhoods surrounding the old lead smelter, which is now a Superfund site. A Superfund site is any land in the United States that has been contaminated by hazardous waste and identified by EPA as a candidate for cleanup because it poses a risk to human health and/or the environment. At this particular Superfund site, over 95% of properties with soil found to have lead above the cleanup level have been remediated. This means that the soil has been removed and replaced with new, clean soil. With the cleanup nearing completion, EPA wanted to ensure that the soil remediation was leading to decreasing blood lead levels in the children that lived in the affected neighborhoods and determine whether further remediation was needed.

Lead is particularly dangerous to children because their growing bodies absorb more lead than adults. Lead has been shown to have negative impacts on children's developing brains and nervous systems. Babies and young children can have higher lead exposure because they often put their hands and other objects into their mouths which can be covered with lead from dust or soil.

Through a collaboration with the Douglas County Health Department, EPA researchers accessed blood lead level data that had been collected from thousands of children living in residences within and bordering the most impacted 27-square mile area in Omaha. EPA combined this data with data on lead in soil and dust inside local homes. Through some analysis, EPA linked the datasets together to create a complete picture of lead exposure in local children, down to the level of exposure that occurred in each home. EPA completed a preliminary analysis of the data, which found that blood-lead levels in local children had dramatically decreased over time.

However, EPA's work is not done. Because there are many factors that may have influenced the drop in blood lead levels, EPA is now working to tease out the effect of soil remediation on the blood lead level decrease by doing a direct comparison of levels of lead in the soil before and after remediation.

Once this analysis is completed, EPA researcher Ellen Kirrane will create a template for the evaluation of environmental data and community blood lead levels that can be used at other Superfund sites. "This will enable us to share our experiences and methods for collecting and analyzing these data so other communities can benefit from similar evaluations," says Kirrane.

"This work may also help EPA further evaluate the EPA's Integrated Exposure Uptake and Biokinetic (IEUBK) model for lead in children at lower blood lead levels than previously evaluated," said EPA researcher James Brown.

The IEUBK model is used to estimate the probability of exceeding specified blood lead levels given that lead exposure can occur through multiple pathways. Since the late 1970s, blood lead levels in children have dramatically decreased due to changes like the phase out of lead in gasoline. Increasing the accuracy of the model at lower blood lead levels that are now more commonly seen is very important, as health effects can occur even at very low levels of lead exposure.

What EPA is learning in Omaha has the potential to help protect children across the country in areas where not as much data is available.

In addition to protecting public health in Omaha, this research could potentially focus scarce resources on the most important sources of lead exposure in other communities.

Gene Gunn in EPA Region 7 says, "This work will help determine whether additional residential soil cleanup actions will be a cost-effective way to further reduce blood lead levels in young children in Omaha and other lead sites across the country. In Omaha alone, it can cost more than $300 million dollars to achieve lower soil lead levels in yards."

This work is another example of how EPA's collaboration with state and local health officials can contribute to a better understanding of Superfund site impacts and decision making that leads to healthier communities.

Three new studies on lead exposure and risk management can inform decisions from national to local scale to better protect children and other vulnerable groups by identifying exposure hotspots and by quantifying how different sources contribute to exposure.

Drinking water isn't the only source of lead exposure. The soil and dust in and around our homes can contain lead. Low levels of lead can also be found in the air we breathe and in some foods. Children, whose brains are still developing, are more susceptible to a host of neurological health effects brought on by lead exposure. The ways that children spend their time can increase their likelihood of exposure—infants and toddlers crawl on the floor and tend to put all sorts of things in their mouths, while older children may spend time playing outside where they too can ingest soil and dust. It's critical that we know how various sources contribute to lead exposure in children.

Estimated contribution of exposure pathways to blood lead levels (BLL) at the national scale. The bars are 10% increments in the BLL distribution. Exposure in the figure is adjusted for bioavailability of Pb in each exposure pathway (Zartarian et al 2017).

EPA researchers have developed a modeling approach that improves our understanding of the relationship between lead concentrations of various sources (drinking water, soil and dust, food, and air) and children's blood-lead levels. Reducing total lead exposure is a long-term goal of EPA, and this model gives us a clearer picture of the lead exposure contribution from multiple sources.

Findings reveal that, on a national scale, drinking water is the most common route of lead exposure among infants (0 to 6 months). But for 1 to 2-year-olds with very high blood-lead levels, soil and dust lead tends to be the main culprit. This isn't to say that toddlers drinking lead-tainted water isn't a concern. If exposure to soil and dust and other sources around their homes results in elevated blood-lead levels, then even limited exposure to lead in drinking water can be problematic—which is why this model's holistic approach is so important.

Paired with additional info like state-collected blood lead level data, the model can help identify communities at greatest risk. The researchers believe that their work can inform decisions to minimize public health risks from national to local scales. This work can foster multi-source lead exposure efforts across government agencies in a coordinated and science-based manner.

The researchers are confident that the model can serve as a valuable tool, but admit that more up-to-date and complete data on various model inputs are needed to refine estimates and reduce uncertainties.

A separate EPA-led studyEXIT may begin to address one of these data gaps—how does lead found in soils relate to the blood lead levels of children living nearby? Lead comes in different forms, and only some of
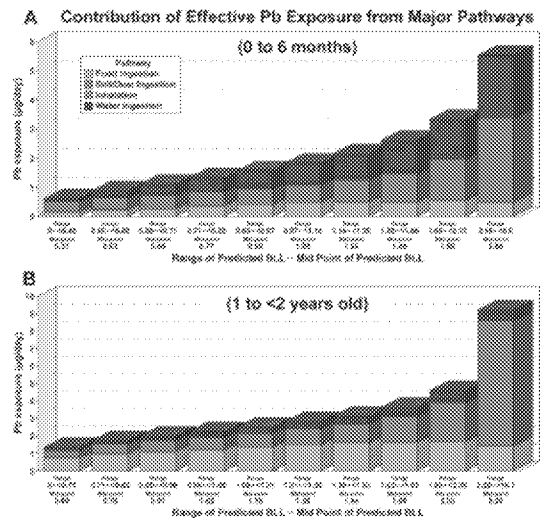
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the lead found in soils can be absorbed by the body and affect our health—this is known as "bioavailable" lead. The study looked at soil samples and blood samples from children living in an area of Philadelphia known to have a legacy of lead contamination. When available, considering the bioavailable portion of soil lead instead of total soil lead can help public health officials improve their lead risk assessments for children.

The work is among the first public health studies based on new bioavailability testing methods for lead developed by EPA to guide site cleanup and revitalization activities. In some cases, focusing on the bioavailable portion of lead can result in significant cost savings (potentially in the tens of millions of dollars) during site remediation, while still ensuring public safety.

Unfortunately, blood lead screening data and lead samples from various sources aren't always available. Even when the data is lacking, public health departments still need ways to identify particularly vulnerable groups and lead exposure hotspots. A third EPA studyEXIT developed a statistical model that predicts blood-lead levels among children across the U.S. at the census tract level by using demographic and socioeconomic data such as age of housing stock, poverty rates, and race. The model results can help officials focus their limited resources on communities most vulnerable to lead exposure. Also, if a community does have blood lead level data, and it is significantly higher than what the model predicts, this might serve as a warning to examine soils, drinking water, or other potential sources of exposure.

The lead work presented in these papers follow other EPA lead-related research efforts including dose estimation modeling (IEUBK model) that has been widely used to support Superfund cleanup efforts.

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EPA researcher Karen Bradham uses a "virtual stomach" that mimics human digestion to determine if arsenic and lead in contaminated soils are bioavailable.

EPA recently validated an innovative new technology to guide the cleanup of soils contaminated with arsenic and lead. The new laboratory method, based on a "virtual stomach" that mimics human digestion, estimates the bioavailability of arsenic and lead in soils quickly and inexpensively relative to animal models. This method will increase the accuracy of Human Health Risk Assessments, potentially reducing remediation costs.

EPA researcher Karen Bradham uses a "virtual stomach" that mimics human digestion to determine if arsenic and lead in contaminated soils are bioavailable.

The method lowers bioavailability assessment costs by enabling simultaneous assessments for both arsenic and lead at contaminated sites. It has been used successfully by EPA Regional offices to develop clean-up strategies across the U.S., saving millions of tax payer dollars in clean-up costs, and interest in the method is growing internationally as well in countries including Taiwan, Australia, and Canada.

EPA scientist, Karen Bradham, Ph.D., along with Clay Nelson and Drs. David Thomas and Kirk Scheckel have been working on a bioavailability method that simulates how the human digestive system absorbs arsenic and lead in soil. "Bioavailability" refers to the amount of a substance that is absorbed by the body's gastrointestinal system following exposure. In May 2017, EPA validated the method after it was shown to meet rigorous regulatory acceptance criteria (OLEM 9355.4-29, April 20, 2017). This means that States and public health risk assessors can use the method during cleanups at EPA Superfund sites and other locations with arsenic and lead contamination issues. In addition to protecting public health, the bioavailability method improves the accuracy of human health risk assessments.

The newly-validated method is sometimes called the "artificial stomach" because it mimics the human gastric system, but in fact, it doesn't look like a stomach at all. It is a clear box that sits on a counter and contains small capped, plastic bottles. Each bottle holds one gram of soil in a clear amino acid solution, with a low pH of 1.5. Researchers flip a switch and the bottles begin rotating end over end in an incubator heated to 98-degress F, matching a person's average body temperature. These conditions are carefully selected to mimic the digestion conditions of the human stomach. After a one-hour extraction period, the amount of lead or arsenic from the soil sample that is solubilized in the artificial stomach is measured to determine the bioavailable fraction of the toxic metal.

"Not all arsenic and lead present in soil are able to be absorbed into humans or animals and can cause harm," Bradham explains. "Certain forms of arsenic and lead are not bioavailable, meaning they are not fully absorbed by the human body" says Bradham.

Many years of work have started to pay off. Previously, if a site contained lead or arsenic in its soil and posed a potential risk, the remedy would be to remove the contaminated soil. Moving this much dirt is expensive. While disposal costs vary, they may account for up-to half of the total remediation costs.

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Scientists and public health officials can now use the artificial stomach method to determine if arsenic and lead in contaminated soils are bioavailable and remove those specific sections of soil. For example, researchers evaluated arsenic-contaminated soil samples from a site using this method and found that only about half the arsenic was bioavailable. Based on this example, only about 90 acres of soil would need to be removed as opposed to the 117 acres that would have been slated for removal using chemical analysis for total metals only. Those chemical analyses are based on measurements of total arsenic levels instead of that which is truly problematic for human exposure. The potential cost savings of the above example: $9 million.

The work of Bradham and her team of EPA researchers continues to progress, both in the U.S. and abroad. The scientists are currently testing how adding soil amendments to soils allows the elements to bind with lead and arsenic, potentially causing them to pass through the human gastric system unabsorbed. These remediation technologies are in the early stages, but are exciting developments for the field of public health.

This research is having an international impact. Researchers around the world are now using this validated method to test the bioavailability of soils. Bradham has trained scientists on using the method in Taiwan. Scientists in Australia, the United Kingdom, and Canada are also using this method.

Bradham explained what she ultimately hopes for the bioavailability method as developments continue worldwide. "We need to keep sharing this method with researchers so they can implement it at contaminated sites to protect human health while saving millions of dollars in clean-up costs and reducing volumes of hazardous material."

In 1992, the City of Madison, Wisconsin, found concentrations of lead in their drinking water exceeding the 90th percentile action level of 0.015 mg/L set by EPA. Lead (Pb) is a naturally-occurring metal that was commonly used in household plumbing materials, such as lead service lines and leaded solder joints, before limits were set on its use in 1986.

Someone fills a glass with tap water. However, in houses built before 1986, lead pipes can still be in use. Lead is rarely found in source water, but it can enter tap water as the water enters pipes with lead in older systems. Since some homes have lead service lines, the water coming into the house may be transported via lead pipes even though there are no lead pipes inside the home. Brass plumbing fixtures can also contain small amounts of lead.

The Madison Water Utility chose to implement full lead service line replacement from 2001 through 2011 to eliminate the most significant source of lead in its water system. In 2003, sixty home taps were monitored after full lead service line replacement. They found that lead levels in the first liter of water were still high at some sites where the lead service line pipes had mostly been replaced within the previous four years. This phenomenon had been seen in other water systems, which had puzzled drinking water practitioners as to why elevated lead levels could persist for so long.

Coincident to the Madison Water Utility studies before and after the lead service line replacement program, lead service lines had been harvested from the water system and sent to EPA scientists. The EPA had the instrumentation and unique expertise to search for clues of lead release in pipe scales. That is, the materials that build up on the inside of pipes display chemical characteristics that reflect the chemical processes occurring in the water system, including the release of lead. The EPA conducted detailed analyses—color, texture, mineralogical and elemental composition--on five lead service pipe samples excavated between 2001 and 2006 from two different Madison neighborhoods.

Before the lead service line replacement program, Madison's water was delivered by an estimated 8000 lead service lines, which had been in service for 75 years or longer. The city's drinking water originated from numerous wells. The first set of lead service lines studied by EPA revealed that a highly insoluble and protective lead oxide compound had formed on the pipe walls. If all lead pipe walls had this formation, high lead releases would not be expected in the water system.

However, the second set of lead service lines came from a different neighborhood in the city. This neighborhood was fed by wells that were rich in manganese and iron. Both manganese and iron can form scales and accumulate metals, such as lead, from upstream sources especially from upstream corroded lead pipes. EPA's results revealed that the accumulation of manganese and iron from the well water onto pipe walls had adsorbed lead and had the potential to crumble from the pipe walls and carry the lead to consumers' taps by means of the scale particulate matter entrained in the water. This finding corroborated with the results of the 2003 study where the higher lead concentration found at consumers' taps was mostly in particulate form. The presence of the manganese and iron scale on the pipe walls was the reason

for high lead release in parts of the Madison water system, before and even after the lead pipes were removed.

As the 2003 residential study had shown, once the principal lead source was removed, it took more than four years in some cases for the accumulated lead to be released, which explains why lead levels remained high after the lead pipes had been replaced. Eventually, removing the source of lead did eliminate the significant lead concentration and achieved compliance with EPA's regulations.

Overall, this research showed that controlling lead exposure from water is more complicated than simply adding corrosion control chemicals to reduce the solubility of lead minerals. Buildup of manganese and iron scale in water pipes should also be considered as a source for accumulating and releasing lead, and other contaminants of concern, into water. What happened in Madison highlights the importance of analyzing pipe scales to understand how lead accumulates and releases into the water over time. This EPA research received both the 2015 American Water Works Association's Distribution & Plant Operations Division Best Paper Award and the overall Journal of the American Water Works Association's overall Best Paper Award.

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Someone fills a glass with tap waterIf lead is found in drinking water, it is important to identify where it is coming from within the water system--that means taking samples at every stage, from the distribution system all the way to the plumbing system inside the home, also known as premise plumbing.

There are many types of sampling techniques available to assess the presence of lead in drinking water. Deciding which one to use depends on what the objective is. Different sampling tools can be used to assess lead exposure, evaluate corrosion treatment effectiveness for different plumbing materials, or identify particularly significant lead contributors that can be removed to mitigate the problem.

A water utility may implement regulatory sampling protocols to meet a trigger or standard - the level above which the water system must take an action. Regulatory sampling isn't meant to diagnose lead sources or assess the risk of lead exposure in an individual residence. However, many utilities do sample drinking water for lead beyond the regulatory requirements to better help identify sources of lead, improve corrosion control treatment, and to inform the public of their risk of exposure.

EPA researchers have identified several sampling protocols to help water utilities assess and mitigate the risk of lead exposure. These techniques fall under two categories--diagnostic water sampling and exposure sampling.

The first technique, diagnostic water sampling, provides a picture of potential lead release in a home's plumbing. This sampling protocol includes a defined stagnation time and defined volumes. It is based on the principle that water samples of a particular volume represent the distance that water travels through the plumbing system. For example, a smaller sample volume provides information about water quality that has travelled a short distance in the home's premise plumbing system, while a larger volume sample provides information about water that has traveled a longer distance. It's important to collect samples of varying volumes, while accurately mapping the volumes, in order to properly identify the potential sources of lead within a home. Long-term sequential sampling taken with the same protocol can help determine treatment effectiveness on individual lead sources in the home.

The second technique, exposure sampling, attempts to capture the amount of lead people could consume by drinking, cooking, or preparing food and beverages with the home's water. Two different approaches to exposure sampling can be used to assess water lead exposure, either at an individual household level or at the community-wide level.

To assess community-wide exposure, researchers can use water quality zone-based random day-time (RDT) sampling. For this technique, samples are collected randomly at enough residences during daytime hours to statistically reflect exposure across a community.

To assess exposure at the individual household level, researchers used side-stream sampling devices and composite samplers. These devices are placed at the point of use, for example, under a kitchen sink. Each time the faucet is turned on, the device diverts a small amount of water to a sample bottle. Once the bottle is full, the sample would be analyzed for lead.

This research shows that there are different sampling techniques beyond the regulatory sampling protocols that can be applied to reach a specific objective, and each can be implemented to solve specific lead-related drinking water issues within a water system.